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Design and 3D printing of the Robot, articulated with 6 degrees of freedom with educational applications

Diseño e impresión 3D del Robot, articulado de 6 grados de libertad con aplicaciones educativas

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Abstract

This work presents the complete manufacturing of an articulated robot of 6 degrees of freedom, with educational applications. With the purpose of increasing the motivation of the students in the significant learning of the subject of robotics. The methodology was developed from the design of each link of the robot in Solid Word, to later print it in 3D, followed by the mechanical and electrical/electronic implementation. In accordance with this, we worked with the mathematical modeling through the RoboAnalyzer software based on the Denavit Hartenberg parameters. To control the robot, so that the student has options to be able to control the robot, a control card was developed which is compatible with: Raspberry, Arduino and PIC microcontroller. In addition to the above possibilities of programming, another programming option is provided to only manipulate the robot with an application on a laptop, tablet or cell phone, these applications are free; it refers to Universal Gcode Sender and Bluetooth Electronics that simulate a teach pendant. With the development of this robotic equipment, it is intended to form integral students in their technological assets.

RoboAnalyzer, Raspberry, Arduino, PIC Microcontroller, Universal Gcode Sender, Bluetooth Electronics

Resumen

Este trabajo presenta la manufactura completa de un robot articulado de 6 grados de libertad, con aplicaciones educativas. Con la finalidad de incrementar la motivación de los estudiantes en el aprendizaje significativo de la asignatura de robótica. La metodología se desarrolló desde el diseño de cada eslabón del robot en Solid Word, para posteriormente imprimirlo en 3D, a continuación, se realizó la implementación mecánica y eléctrica/electrónica. En concordancia con esto se trabajó con el modelado matemático a través del software RoboAnalyzer basándonos en los parámetros de Denavit Hartenberg. Para controlar el robot, de manera que el estudiante tenga opciones de poder controlar el robot, se desarrolló una tarjeta de control la cual es compatible con: Raspberry, Arduino y microcontrolador PIC. Además, de las anteriores posibilidades de programar, se brinda otra opción en programación de sólo manipular el robot con una aplicación en laptop, Tablet o teléfono celular, estas aplicaciones son libres; se refiere a Universal Gcode Sender y Bluetooth Electronics que simulan una teach pendant. Con el desarrollo de este equipo robótico se pretende formar estudiantes integrales en su haber tecnológico.

RoboAnalyzer, Raspberry, Arduino, Microcontrolador PIC, Universal Gcode sender, Bluetooth Electronics

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Introduction

The education in some institutions that do not have equipped laboratories, practical subjects are offered, only with theory or simulations, this affects the student in their academic and work performance. The subject of robotics is very necessary in the Curriculum Vitae (CV) of engineers, as it is very required in the industry [1]. Because all industrial processes are being automated by robots, which have the tendency to replace man in heavy, monotonous or dangerous tasks.

Great scientists, engineers, athletes etc. have always said that practice makes the difference [2]. This leads us to understand that our educational institutions must teach the subjects in a practical way, with industrial equipment as close to reality as possible. For some institutions this equipment is complicated because they are very expensive or very difficult to install and a mistake could cause material or physical damage. We questioned how to innovate the way in which the subject of robotics is taught and learned, simulations are used and correct for the teaching of direct and inverse kinematics, however, the physical equipment is always required, so we implemented the articulated robot of 6 degrees of freedom to provide great support to the subject of robotics, and that students can program and manipulate a robot professionally and/or remotely as they would with an industrial robot, as well as provide options to program it through controller cards and increase student creativity so they can create projects that have an impact on their communities.

Objective

To design, implement and control an industrial scale robot for educational and training purposes.

Methodology

Robot design and printing

We developed a robot with our own design inspired by the BCN 3D ROBOT robot [3] with some improvements adapted to our needs, Figure 1.

For the 3D modeling of the robot we used free software such as BLENDER (Figure 2) and also Solidworks software since they are suitable for our design needs of each mechanical component.

Figure 1 3D model of the robot (planetary gearing system)

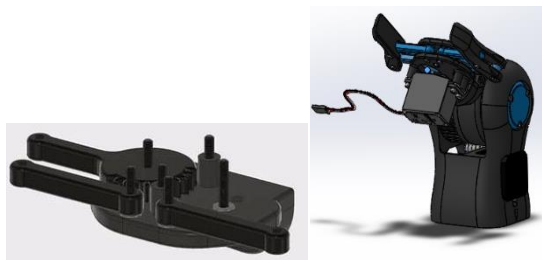


Figure 2 3D modeling of the gripper and the BCN 3D robot

Having the robot design to scale with the correct dimensions and tolerances of each part, its mechanical implementation was simulated to corroborate that the assembly will be correct, Figure 3.

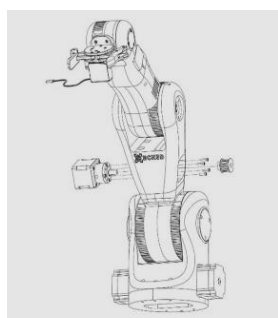


Figure 3 Mechanical implementation of the BCN 3D robot

Once it is corroborated that all the pieces match perfectly, the printing of each one of the pieces in 3D printers begins, with an approximate printing time of 5 days (figure 4).

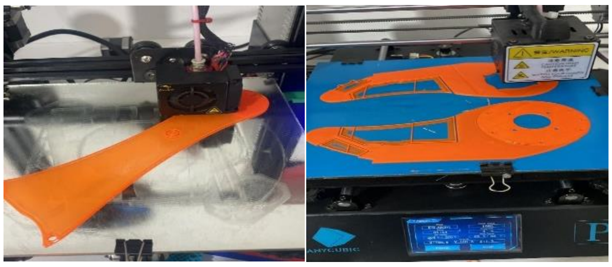


Figure 4 3D printing of the rotating column

Mechanical System

The 6 degrees of freedom articulated robot is composed of high performance motors with excellent flexibility and reliability. It is a unique slim design that reduces the space it occupies, allowing it to work in very narrow spaces. The robot is kept in balance on its base, thanks to a mechanical differential. The components of the ROBOT are as follows:

- Type: Articulated
- Number of axles: 6
- Degrees of freedom
- Maximum load: 20 Kg
- Minimum load: 5 Kg

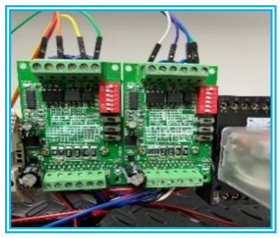
Electrical/Electronic System

Each joint of the robot is controlled by stepper motors that allow them to have independent movements with a gearing system that increases the torque and creates a natural motion [4,5,6]. Table 1 shows the stepper motors that control the Robot's movements:

Stepper motor	Features	Source: (STEPPERONLINE 2022).
Nema 23	Bipolar 1.8 grados 2.4Nm (340oz.in) 1.8A 4.95V 57x57x104mm 4 Hilos.	
Nema 14	Bipolar L = 33 mm with gear ratio 51: 1 Planetary gearboxes.	
Nema 17	Bipolar L = 33 mm with gear ratio 27: 1 Planetary gearboxes.	

Table 1 Motor characteristics

The controllers or drivers used in the control of the motors are shown in Figures 5, 6 and 7:

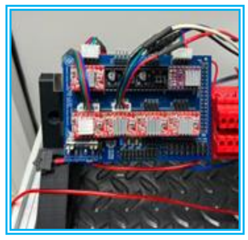


Driver TB6560
- Operating Voltage: 10 – 35 Vcd
- Current setting control
- Max Current: 3 A
- Pitch adjustment: 1, 1/2, 1/8 y 1/16
- •Compatible con shield match3 y Arduino (GRBL)

Figure 5 TB6560 Driver mounted in the control section

Driver A4988
• Input Voltage 3.3v y 5v
• Maximum Current 2A (Heatsink and ventilation).
• Maximum Voltage: 35v
• With heatsink
• Step resolution: 1, 1/2, 1/4, 1/8 y 1/16.
• Size 20 x 15 mm.

Figure 6 Driver A4988



Driver 8825
-Logic voltage: 3.3V - 5V DC
-Power Voltage: 8.2V - 45V DC
-Current: 1.5A per coil (max. 2.2A)
-STEP and DIRECTION control interface
-6 resolutions: full step, half step, 1/4, 1/8, 1/16, 1/32, 1/16, 1/32
-Potentiometer allows you to limit the maximum current, so you can use higher voltages and achieve better resolution.
-Regulator included

Figure 7 Driver 8825 montado en la sección de control.

Control System

For the control of the robot, a control mother board was designed that is compatible with Arduino, PIC Microcontroller, Raspberry, in order to expand the options to control the actuators. Therefore, the following characteristics of this board are shown below:

- Controls up to 8 stepper motors simultaneously.
- Connection of up to 8 limit switches for homing motors.
- 1 PWM output signal for tool control.
- 12V auxiliary pin.
- 5V auxiliary pins.

This board is an Arduino shield and is connected to the Arduino through the digital pins. The complete electrical schematic is shown in Figure 8.

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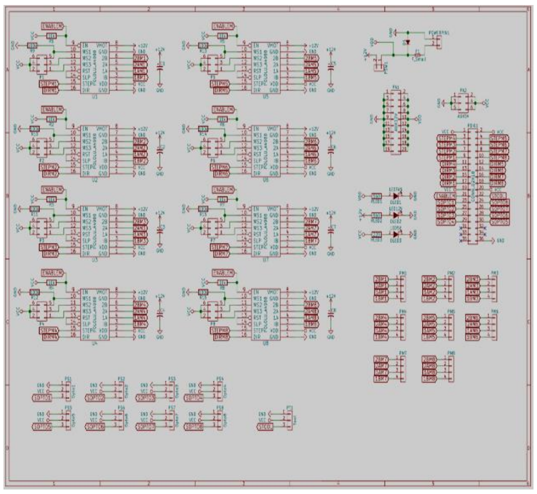

Figure 8 Control board electrical schematic diagram

In addition, for the control system, the cards were adapted to provide 2 robot manipulation options: the UGS program (Universal Gcode Sender) [7], the operator can manipulate the robot by means of commands programmed in G code (numerical control), shown in Figure 9.

Figure 9 UGS software

It also provides the function of being able to manipulate the robot with a smartphone or tablet through the Bluetooth HC-05 module installed on the board, this is controlled through the free access application Bluetooth Electronics, see figure 10.

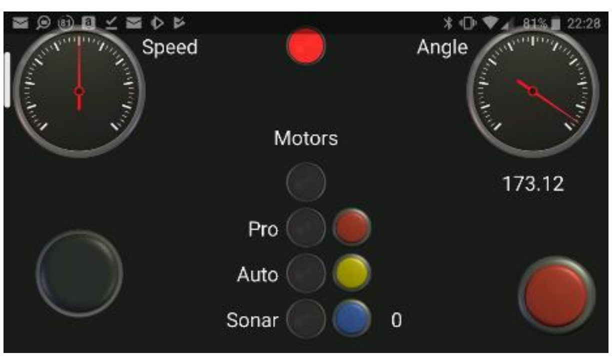

Figure 10 Aplicación Bluetooth electronics

Mechanical and Electrical/Electronic Implementation

Once we have each of the robot parts printed, we start with the mechanical assembly and electronic wiring, as shown in Figures 11 and 12.

Figure 11 3D printed parts (oscillator arm and neutral arm)

Figure 12 Stepper motor wiring

Results and tests

At the conclusion of the mechanical and electrical/electronic implementation stage, Figure 13 shows the Robot that is fully assembled and ready for programming.

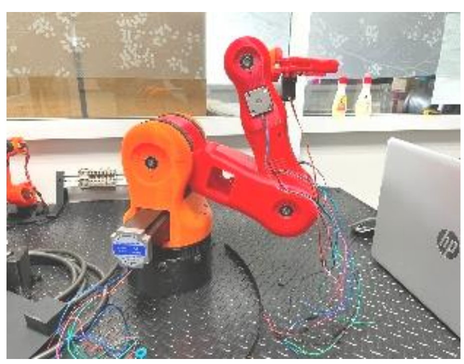

Figure 13 Implemented robot

The installation in the robotic trainer cell was carried out with the purpose of checking that each of the robot joints correspond to the dynamic movements according to the requested programming [8], this is shown in Figure 14.

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Figure 14 Trainer robotic cell

Simulation of the mathematical modeling

For the mathematical modeling, RoboAnalyzer was used, which is a free software to simulate the mathematical modeling of the robot, shown in Figure 15.

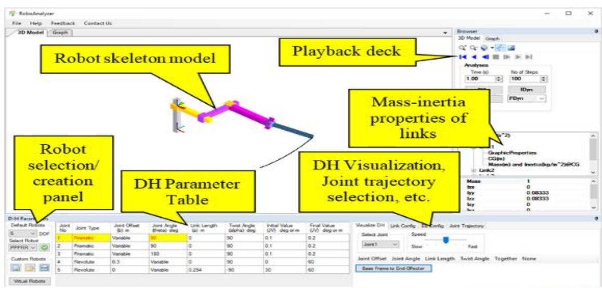

Figure 15 Main screen of the software, image from the cited article
Source: [9]

The mathematical modeling and simulation presented allow predicting the motion of each of the links without having to go to the physical system to obtain their final matrices [10], the calculation is based on the Denavit Hartenberg (DH) parameters. In addition, robot kinematics requires matrix algebra, coordinate transformations and multivariate equations [9]. Figure 16.

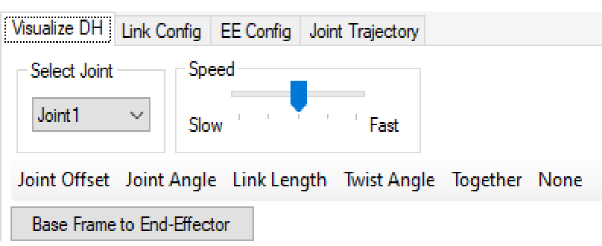

Figure 16 Parameters based on Denavit Hartenberg

When DH parameters are described mathematically, they are associated with coordinate transformations; the next thing is to understand their effect on the physical configuration of the robot, Figure 17, i.e., how a change in DH parameters can affect the robot architecture and vice versa. [9].

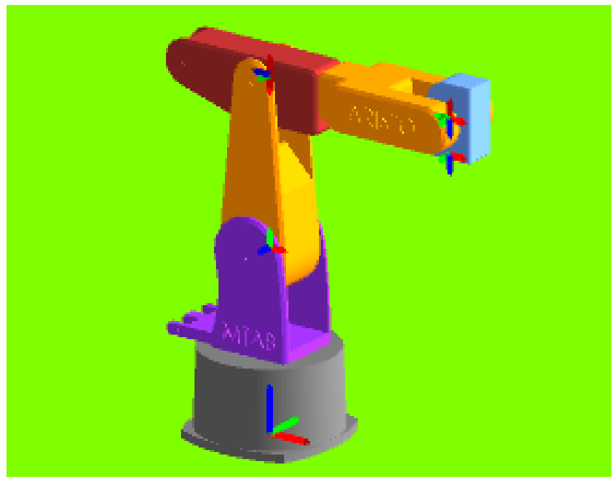

Figure 17 Visualization of DH parameters in RoboAnalyzer of the robot BCN-3D

To visualize the shapes of the robot's motion, the motion matrices to be moved by each joint and link are calculated. Otherwise, kinematically and dynamically, they are the same. Then the link parameters can be varied by changing the DH parameters to see the effects on the kinematic and dynamic performance.

This provides students with a way to explore variations on the given architecture of an industrial robot. [9].

i	$b_i(m)$	$\theta_i(°)$	$a_i(m)$	$\alpha_i(°)$
1	0	0	0.1	0
2	0	0	0.125	0
3	0	0	0.1	0

i	$b_i(m)$	$\theta_i(°)$	$a_i(m)$	$\alpha_i(°)$
1	0.1	0	0.1	90
2	0.1	0	0.125	90
3	0.1	0	0.1	90

Table 2 Variations in the BCN-3D robot articulations

As in this case the BCN 3D robot is a 6 degrees of freedom robot, we select the 6 degrees of freedom and the similar robot type. The chosen one is Aristo, and we verify that it is the required model (figure 18), therefore, we click on the green button, figure 19. The values are added in DH table (figure 15) of each of the links. Figure 19.

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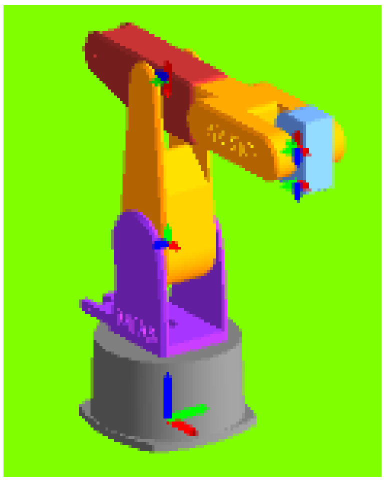

Figure 18 Aristo model, similar to the robot BCN 3D

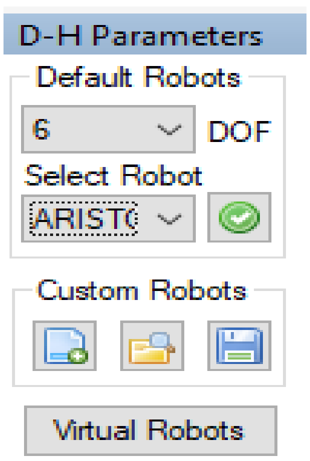

Figure 19 Selection of robot characteristics

Joint No	Joint Type	Joint Offset (b) m	Joint Angle (theta) deg	Link Length (a) m	Twist Angle (alpha) deg	Initial Value (JV) deg or m	Final Value (JV) deg or m
1	Revolute	0.322	Variable	0	90	0	60
2	Revolute	0	Variable	0.3	0	90	60
3	Revolute	0	Variable	0	90	180	150
4	Revolute	-0.375	Variable	0	90	-180	-200
5	Revolute	0	Variable	0	90	-90	60
6	Revolute	0.063	Variable	0	0	0	60

Table 2 Table to insert DH values for each joint and linkage

Once the required parameters have been configured, select the FKin button to update the program memory. Then we select the play button to execute the required robot motion program. Figure 20.

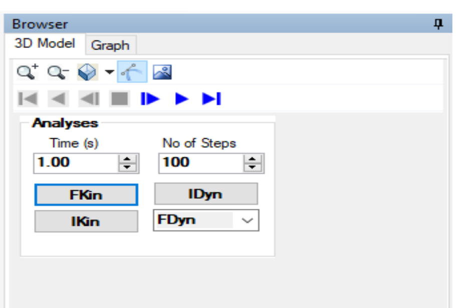

Figure 20 Buttons for executing robot movements

Then, the BCN 3D robot displayed on the screen will execute the calculated strokes of each joint according to the data entered in the DH table. Figure 21.

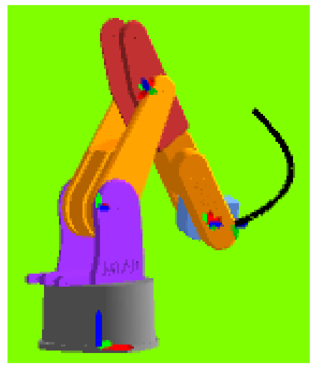

Figure 21 Movement of each joint of the robot

Subsequently, to analyze the resulting matrix, select the Link Config. option and choose the joint to be analyzed to display its DH matrix. Figura 22.

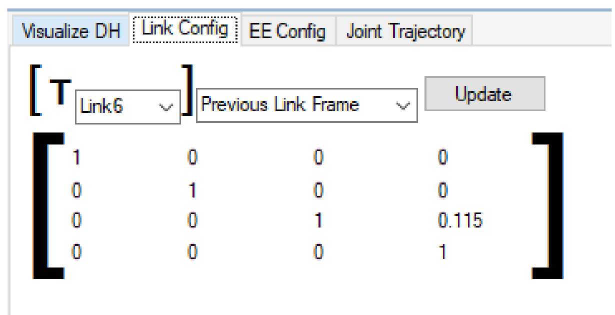

Figure 22 Display of the selected link matrix

The numerical values of the 4 × 4 homogeneous transformation matrices (HTMs) are necessary for kinematic and dynamic analyses, as they describe the position and orientation of the robot links. The RoboAnalyzer software and the HTMs for different links are available to the user in the GUI. This would allow them to validate their results, especially in the classroom and during practical exercises. [9,11]. Figure 23.

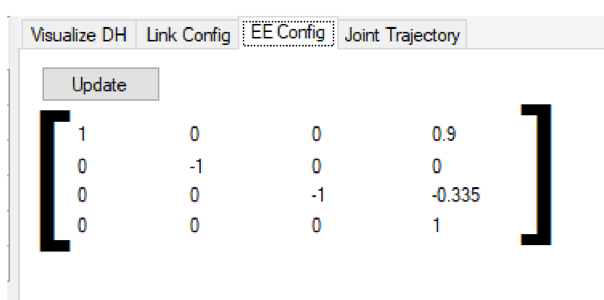

Figure 23 Homogeneous transformation matrix

The physical robot will match the movements, as the traces observed in the simulation, because the degrees that were entered in the DH table of the RoboAnalyzer software for each joint are the same degrees that were entered in the Universal Gcode Sender (UGS) software.

The trajectory of the cycloidal traces of the position of a joint and its corresponding velocity and acceleration are shown plotted in the Graph option. Figure 24.

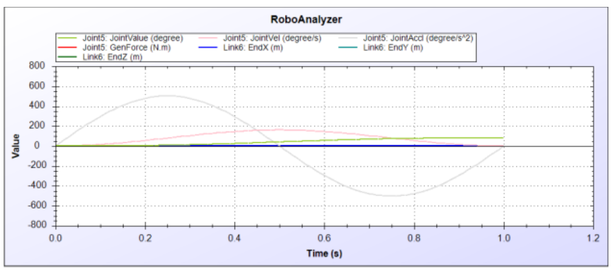

Figure 24 Plotted values of the final matrix of the BCN 3D robot

In this sense, when interpreting data and information, the mathematical modeling of a physical system refers to the process of obtaining a set of equations of this. From the point of view of the scope of what is required to simulate the system, this is how the trajectories of each link are obtained by means of mathematical equations. [9,11,12].

Conclusion

In this project the proposed objectives were satisfactorily achieved, with the purpose that the student interacts with equipment that they will find in the industry once they graduate, so that they will already know them physically during their academic preparation. So, the Robot was designed and implemented, the mathematical modeling was also obtained, using the RoboAnalyzer software, thus validating results that were normally obtained from the homogeneous transformation matrices of the kinematics and dynamics of the robot movements, to something tangible, such as programming with cards like the PIC microcontroller, Arduino and Raspberry Pi Pico and also manipulate the robot, even with applications with the cell phone,

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